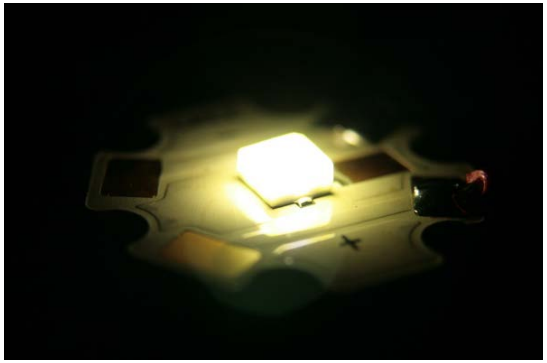
Quantum Dot Downconverters: LED Package Integration

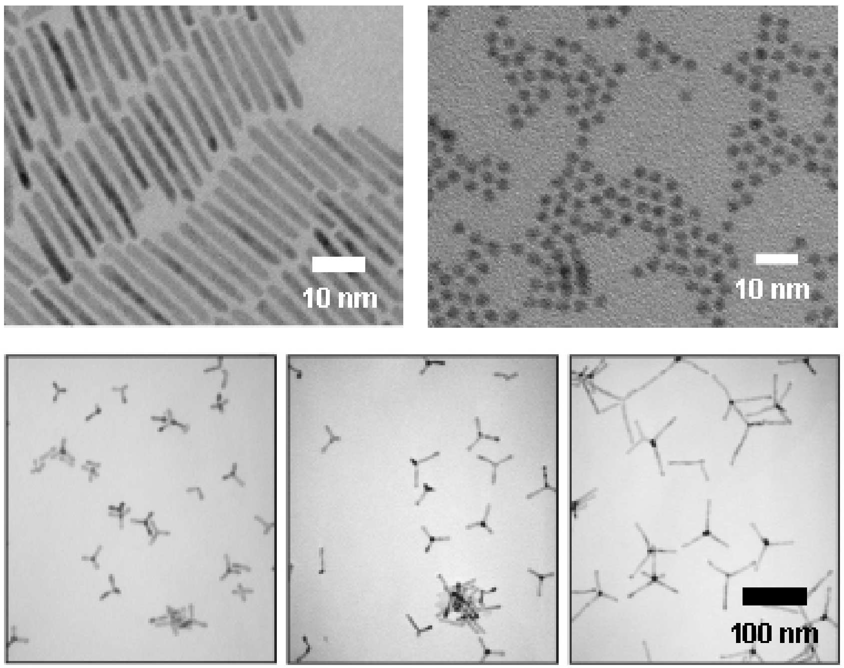


Julian Osinski, Ph.D.
VP of Product Marketing
Pacific Light Technologies

DOE SSL R&D Workshop, Tampa, FL, January 29, 2014

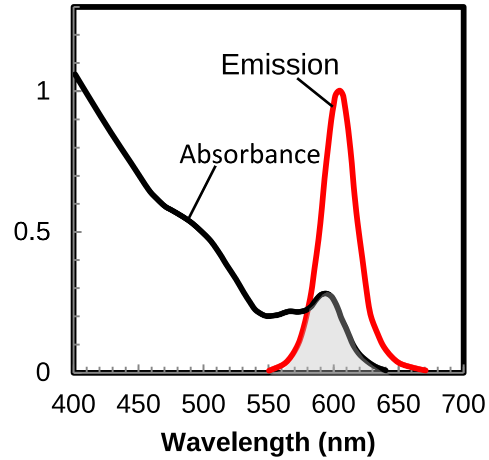
QD Nanoparticle Emitters

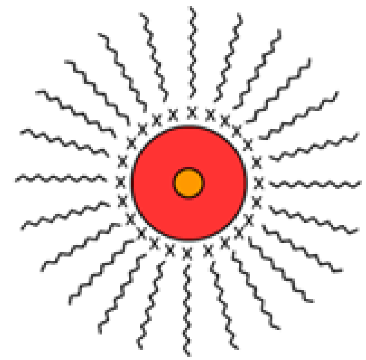
CdS, CdSe, CdTe



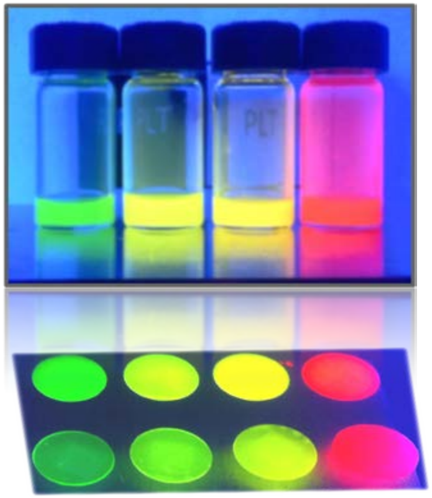
Murray, C. B.; Norris, D. J.; Bawendi, M. G. *JACS*, **1993**, 115, 8706
Alivisatos, A. P. *Nature Materials* **2003**, 2, 382

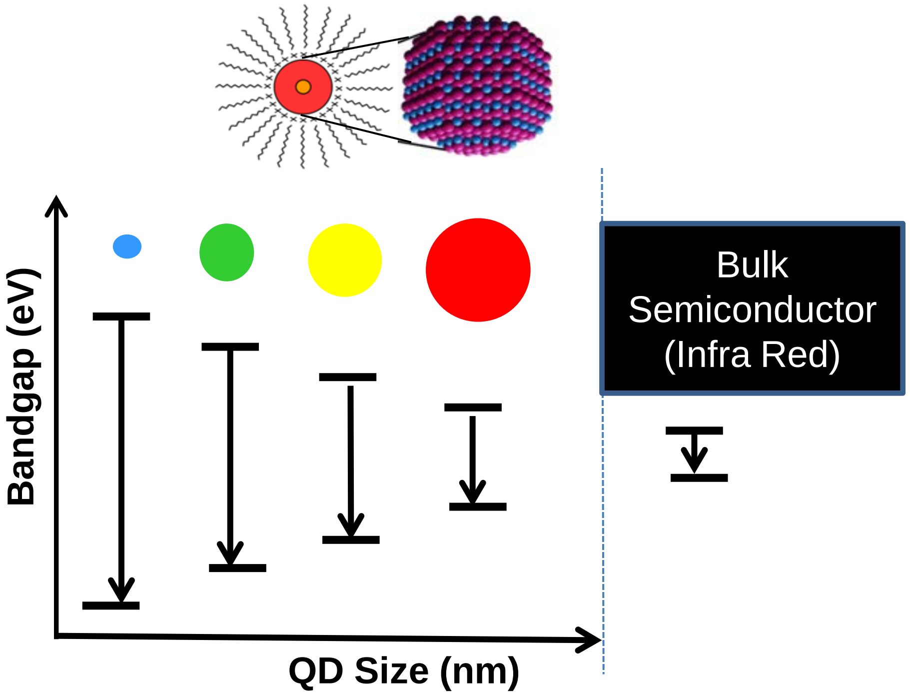
Optical properties controlled by size, materials, shape





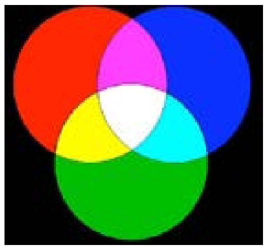
Advantages of QD downconverters

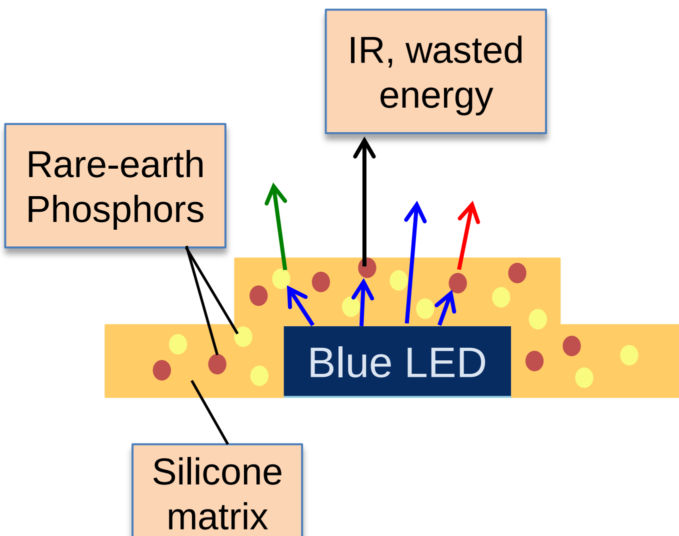


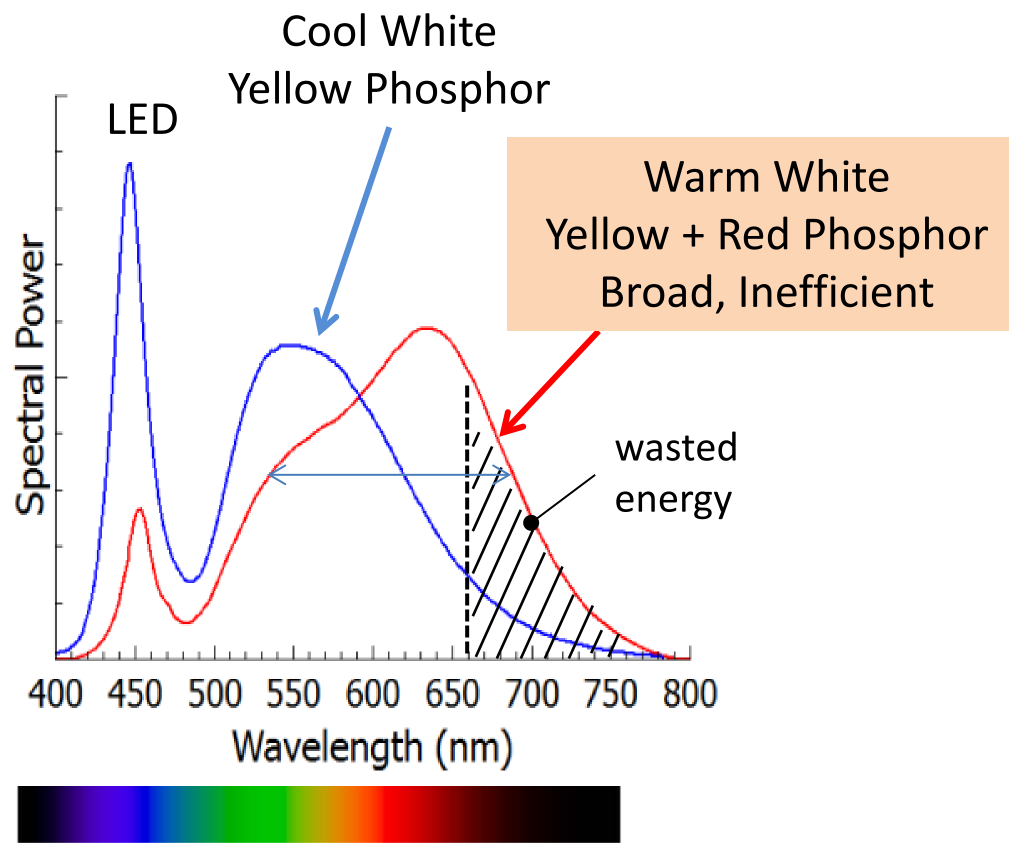


- *Precise peak emission placement (± 2 nm)*
- *Very narrow emission peaks (< 35 nm)*
- *Fast radiative decay times—(ns compared to µs)*
- *Very high efficiencies*
- *Soluble--Composites can be clear*

White Light LEDs: How It’s Done Today



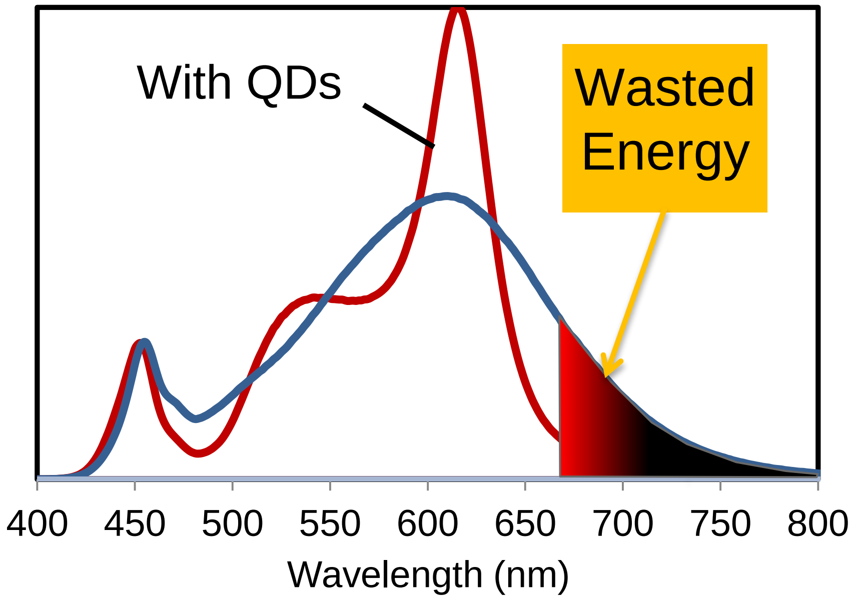




Blue LEDs + Phosphors Produce White Light

Why QDs in LEDs?

QDs Simultaneously Increase Efficacy and Improve Color Quality



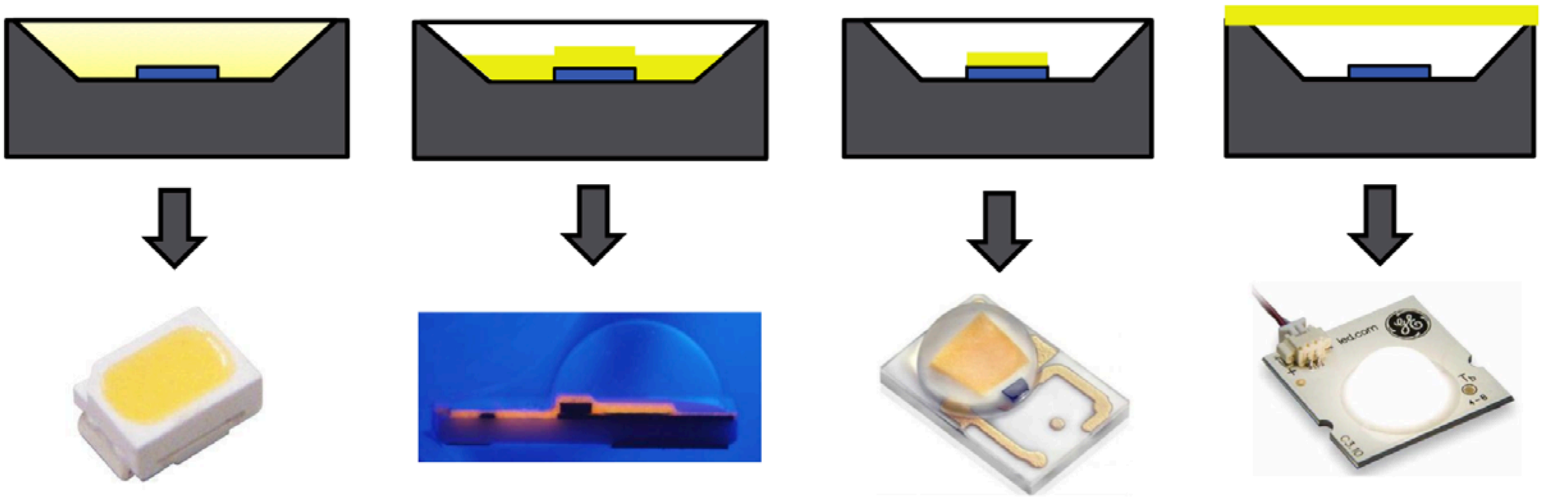
- **Red or other wavelengths where you want them**
- **Efficacy improvements thanks to narrow spectrum: 20-40% benefit for WW**
- **Customizable spectrum allows improved CRI: >90 easily obtained**

<u>QDs Reduce System Cost</u>

- Fewer LEDs required in a luminaire
- Smaller drivers and heatsinks required

Replacing Phosphors with QDs in LED Packages

Dispersion:	Conformal Coating Package level:	Conformal Coating or Pre-Form – Chip only:	Remote Phosphor:



Dispersed Phosphor (Cree)	Conformal coating on a Luxeon Rebel by Philips Lumileds. The phosphor coating is visible under UV light	Amber emission with a ceramic nitride phosphor attached to a blue die (Philips Lumileds)	High Power LED with remote phosphor dome (Source: GE)

Source: Yole

Quantum dots must perform on-chip to contribute significantly to solid-state lighting

On-chip QDs: Practical Requirements

Quantum dot materials need to stand up to a host of environmental demands:

- Mixing into silicone: room air, ambient conditions, possibly with phosphors or fillers
- Curing (150C, 1-2hrs)
- Lens Molding
- Solder Reflow (260C, ~10 sec)
- Non-hermetic use condition at high temperature and blue flux

Choice of Silicones

- Two major types in common usage
- Each LED manufacturer has their favorites
- Ideally, QD performance is independent of the matrix
- Other considerations: viscosity, hardness, darkening…

	Methyl	Phenyl
Refractive Index (n_p)	1.41	1.53-1.54
Transmittance	Excellent	Excellent
Light Stability	Excellent	Very Good
Gas Barrier	Fair	Very Good

Phenyl encapsulants may enhance efficiency of light extraction of LEDs.

Source: Dow Corning

Typical Two-part Silicone System

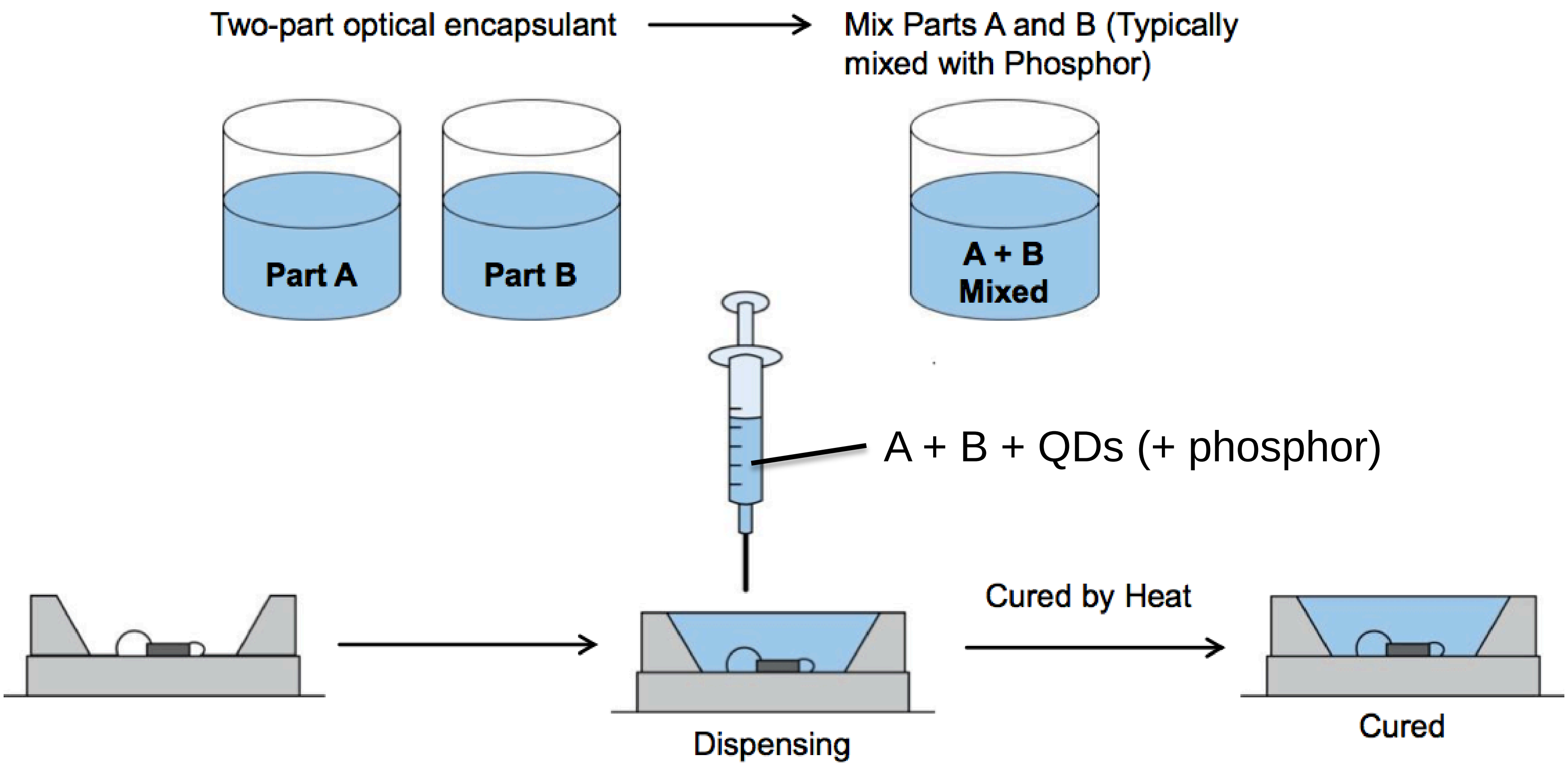


Image Source: Dow Corning

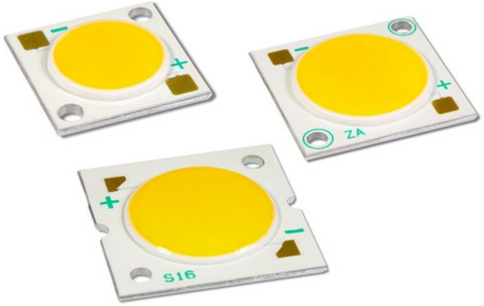
QD Concentration Control

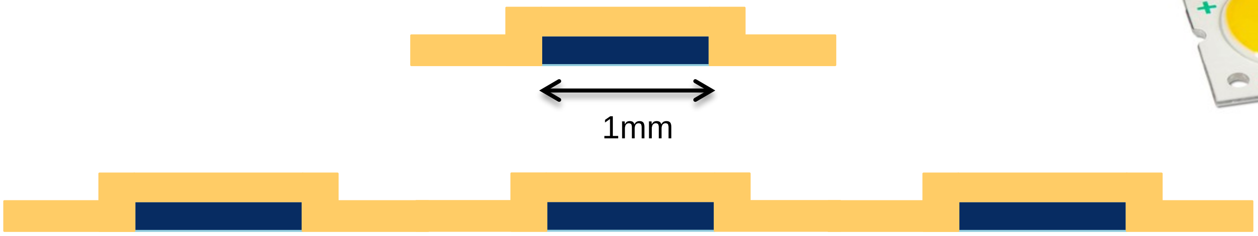
- Concentrations must be adjusted to accommodate various thickness requirements of the silicone film above the chip.
- Typical film thickness range 50-400 microns
- The **number-density** of QDs above the chip determines the conversion ratio
- The **mass** per unit area or volume of the QDs required is very different than that of phosphors and in total is ***100’s of times less***!

Quantum dots can be applied on-chip using most any application techniques and package types

Spraying, printing, dispensing, etc:

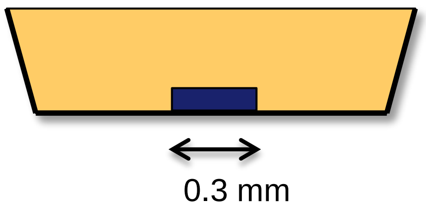
1. Conformal or near-conformal coatings: most high power SSL packages use this approach
   - Includes COB packages and arrays
   - Customizable concentrations for various thicknesses
   - Highest fluxes and temps
     - 100+ W/cm^2, >125C



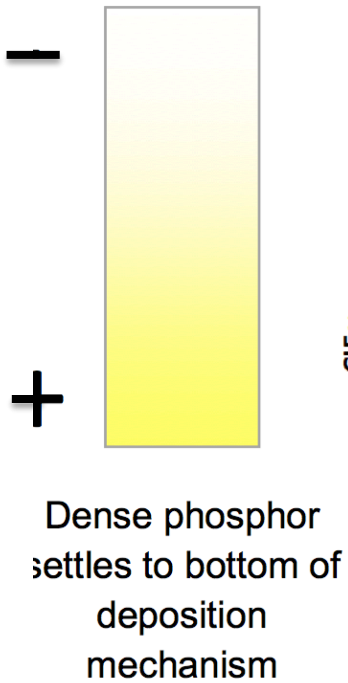


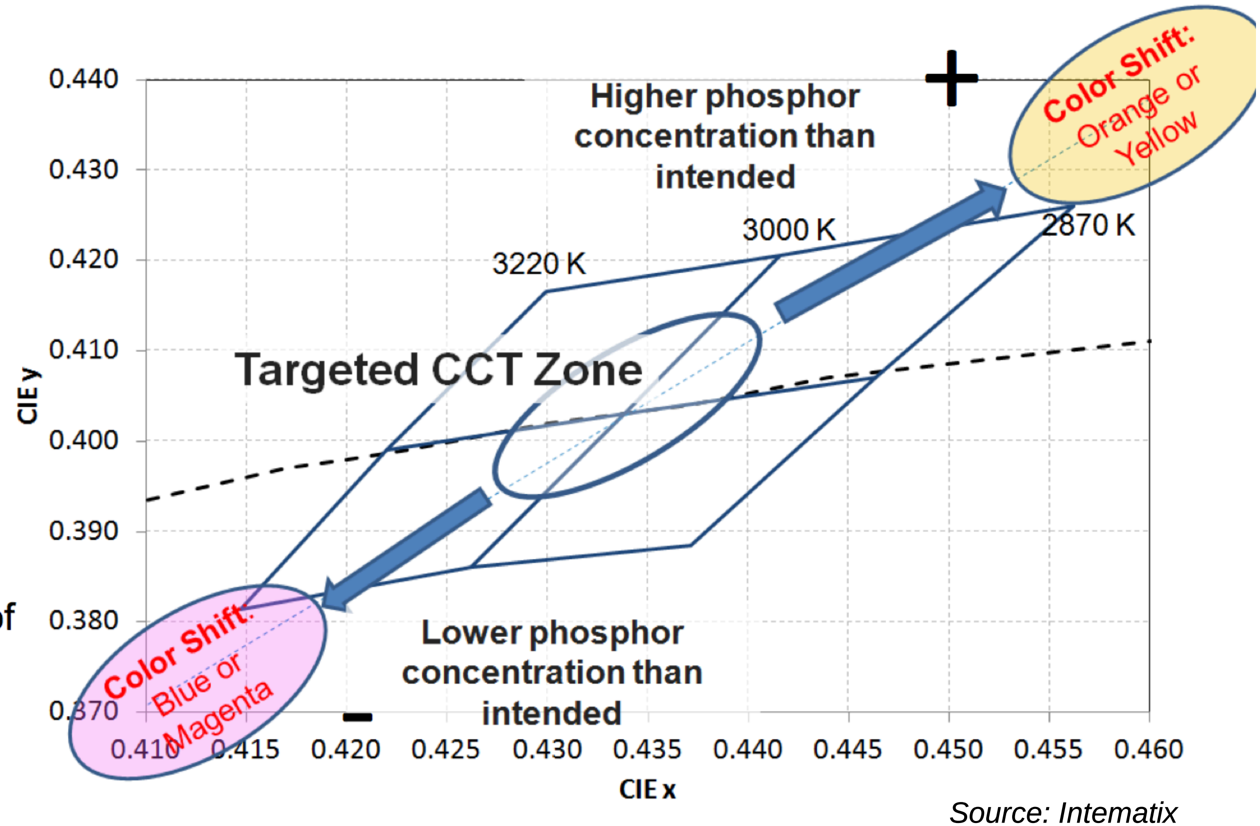
Package Types II

2. Volume casting: "Goop in a cup"
   - High volume, mid-power package design
   - QDs don't settle!
   - 20-60 W/cm2, ~110C
   - This pkg type also used for display backlights



Settling Issues with Phosphors

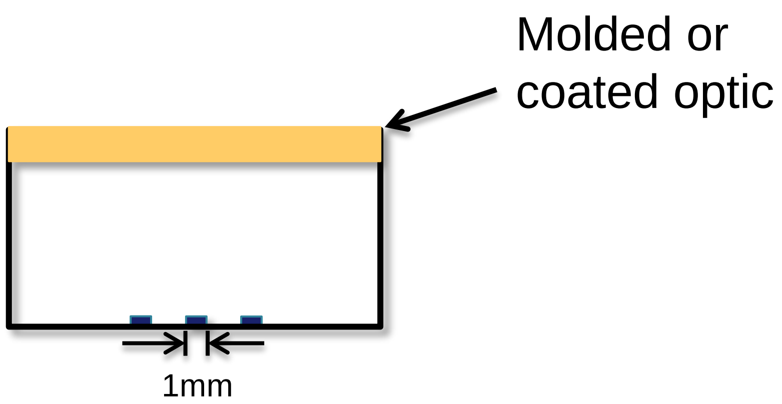




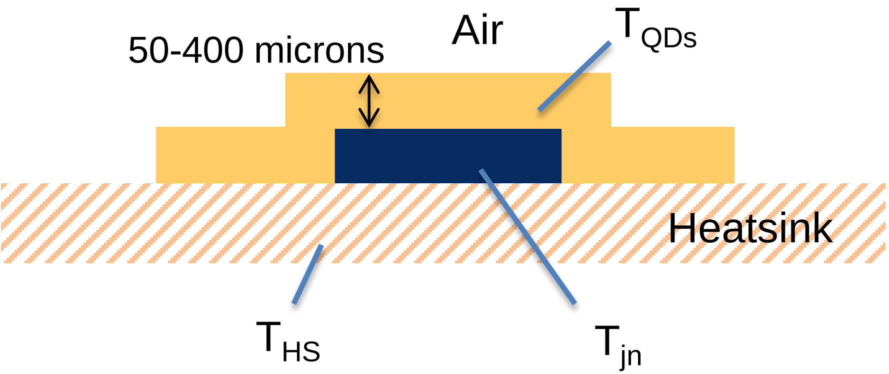
This problem goes away with QDs

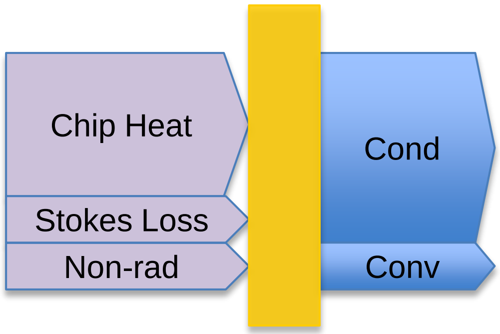
Package Types III

3. Remote Optic
   - Lowest temperature and flux conditions
     - <10W/cm^2, <100C typically
   - 10% or more higher efficiency claimed due to photon recycling
   - Most cost-sensitive, uncertain market acceptance



Contributions to Heating



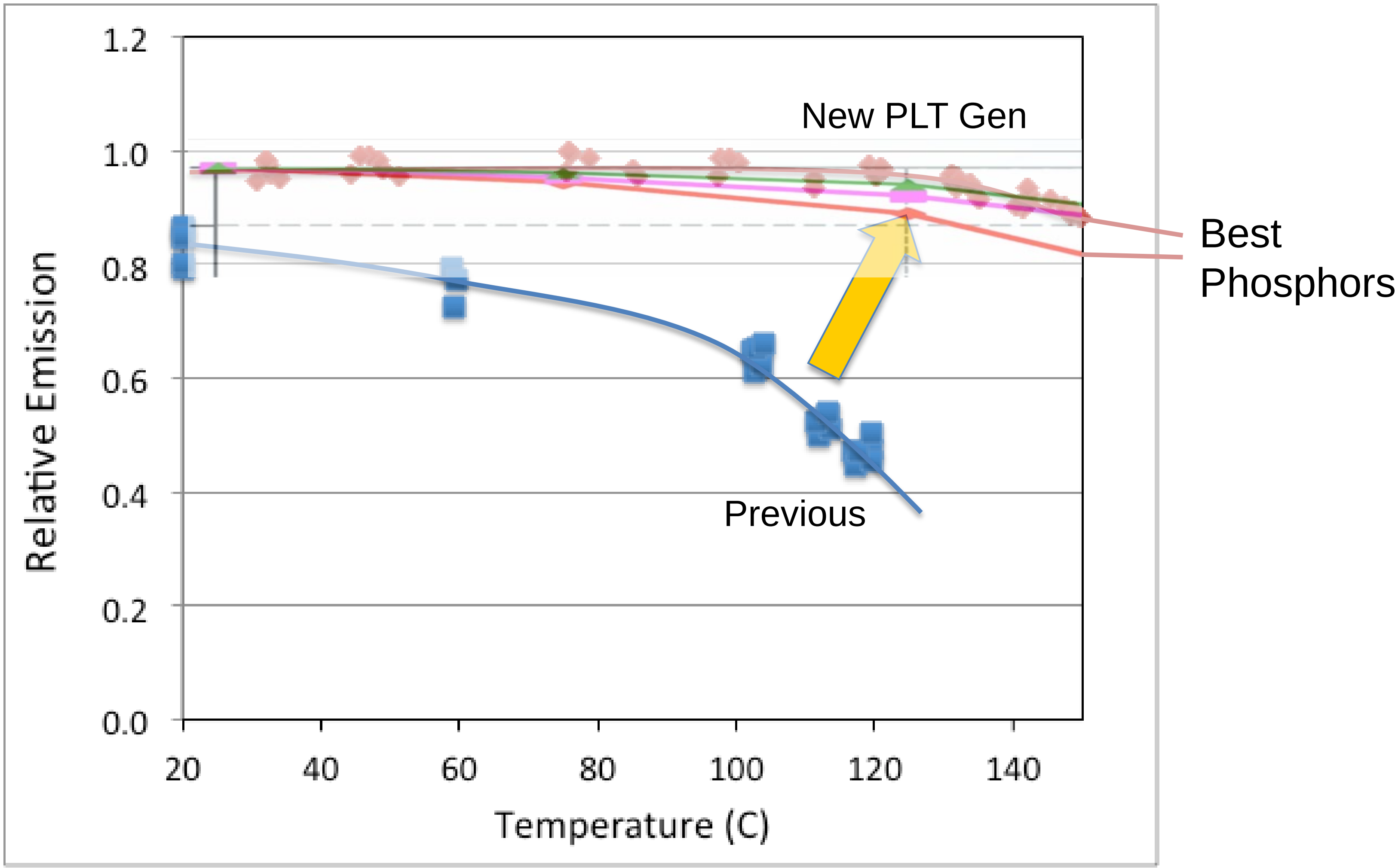


QD temperature is a function of:

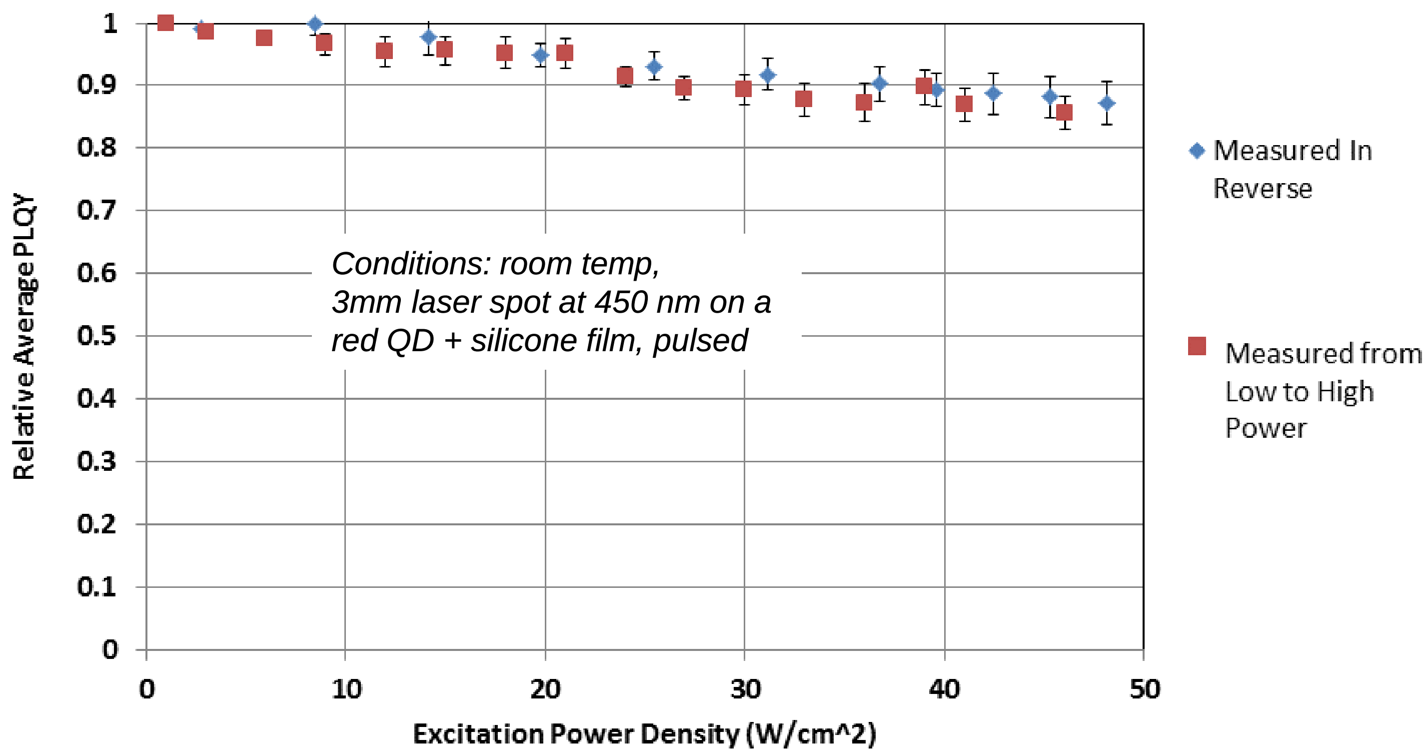
- Conductive heating from chip
- Stokes loss
- Non-radiative losses, quantum efficiency < 100%
- Conductive/convective cooling from surfaces

Net temperature rise for mid-power LEDs typically 10-20C over T_{jn}
Measurable by thermal camera or monitoring wavelength shift of QD emission.

Temperature Dependence: Low thermal quenching



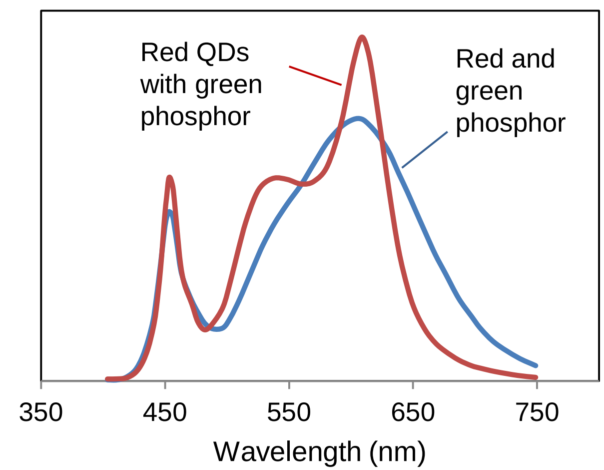
PLT Results on Intensity Dependence



- For PLT materials, no cliff observed up to 50 W/cm, measured in silicone at ambient conditions
- Other tests have been made out to 1000 W/cm2

On-chip QD requirements: Summary

- Compatibility with silicones and mfg processes
- Tolerant to high temperatures
- Tolerant to high pump intensity
- Maintenance of high quantum efficiencies over life
- Ideally without a hermeticity requirement



Actual operational data

Thank you!

Julian Osinski, Ph.D.

Pacific Light Technologies

julian.osinski@pacificlighttech.com

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